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ARTICLE

EXPERIMENTAL STUDY ON BOLTED SHEAR CONNECTOR ENHANCEMENT IN PRECAST COLD-FORMED STEEL-FERRO CEMENT FOR COMPOSITE BEAM SYSTEM

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ABSTRACT

Background: *This work presents the experimental tests carried out to evaluate the behaviour of shear connectors between cold formed steel (CFS) beam and ferrocement slab. The proposed section is an innovativepre-cast slab of ferrocement integrated together with CFS by means of shear connector to form a composite beam system. Six push-out test specimens of cold-formed steel lipped channel sections connected with ferrocement slab were tested. Two different types of shear connectors comprised of 10mm and 12mm diameter of bolts were used in the experimental tests. The standard push-out test, as defined in Eurocode 4 [1], was adopted. The connection behavior was analysed in terms of its load-slip relationship and the failure mode. The effect of varying parameters such as the number of layers of wire mesh inferrocement slab and the size of bolt diameter used is presented and discussed. An analytical analysis using ANSYS (version 11) program and theoretical analysis (Eurocode 4) were carried out to validate the experiment results. The results of comparing the experimental, theoretical and numerical values proved to have good agreement.*

KEY WORDS
Cold-formed steel, Composite beams, Ferro-cement, Finite Element Method, Push-out test, Shear connector

INTRODUCTION

Composite construction in which steel beams and girders act compositely with concrete slabs have been used in bridge engineering [2] and building construction [3, 4] for several decades. The most widely employed composite construction system referred to as hot-rolled steel sections with shear studs as connecters between slab and beam [5-7]. Concrete is usually poured onto a corrugated cold-formed steel sheet, which is in turn connected to the supporting beams through shear studs as connectors. The use of this type of cold-formed steel as composite slab system with shear stud connectors has been well established in North America where details of design guidelines are available in both American and Canadian design codes. The use of cold-formed steel sections such as an I-section as composite floor joists in slab systems has been limited despite the advantages of reduced slab thickness as compared with the typical concrete slab alone [8]. One essential element of these composite systems is the shear connection between steel and concrete. Since the steel sections are light gauge, the welding of shear studs is not recommended [9]. The main objective of this study to choose the best available shear connector proposed in this study for the possible use in pre-cast composite beamof cold formed–ferrocement system. This study also intends to model the tested specimens as a three-dimensional finite element model using ANSYS 11 by simulating the behavior of the bolted shear connectors [10-14] [21]. A push-out test arrangement was modeled for linear and nonlinearity behavior for all tested specimens by taking into consideration the modes of failure, the ultimate strength, and the load–slip behavior of the shear connectors. The results of the present FE model are compared with experimental push-out tests and agreed well.

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MATERIALS AND METHODS

[Fig. 1] shows the details of cross-section for the push-out test specimen. The basic specimen configuration and construction are based on Eurocode 4 [1] and BS5400 [15] [20] [22]. The width of the ferrocement slab was 400 mm, 400 mm height and the thickness was 50 mm. The I-section of the CFS beam was formed by placing lipped C-channels back-to-back with the top flanges attached to ferrocement slab by the proposed bolted shear connector as shown in [Fig.2]. The bolt was fixed by two nuts; the first was installed on the inside whereas the second was installed on the outside surface of the top flange of CFS section. The top flange of CFS section firmly holds together by the two nuts as shown in [Fig.2]. The welded wire fabric reinforcement (Skeletal) consists of 5 mm diameter bar with spacing of 80 mm x 80 mm were installed between 2, 4 and 6 layer of wire mesh (1.2 mm diameter) as shown in [Fig. 1] and illustrated in [Table 1]. A recess of 50 mm in height was provided between the bottom of the Ferrocement slab and lower end of the cold-formed steel section to allow for slip during testing. Both sides of the flanges of the I-beam for each specimen were connected with Ferrocement slab to form a composite system. The test procedure was based on EC4. The locations of transducers and instrumentation setup are shown in[Fig. 3].

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Material properties

The main components of materials used in the tested specimens comprised of cold-formed steel section, wire mesh and bolts. The results of these tests are given in Table 2. The ferrocement slab was designed to meet the compressive strength of 35N/mm2 of grade C35.

DESIGN EQUATION

The tested specimens are expected to fail by two types of failure modes. The specimen is expected to fail by ferrocement crushing into embedded area where stresses in ferrocement due to applied load exceeded the design stresses of the ferrocement. However, when the ferrocement is very strong, the shear connector may possible to fail due to bolts bearing or shearing-off. The shear connector is expected to fail when section of the shear connector failed to resist the stress developed due to the applied load. For shear connectors with headed studs, the predicted strength capacity was calculated based on the equations given by Eurocode (EC4). However, in this study the same formula are used to predict the expected load failure for the proposed bolted shear connector.

Table 1: Specimens for push-out test

<table>
<tr><th>Specimen</th><th>Type of shear connector</th><th>Diameter (mm)</th><th>Number of layer</th></tr>
<tr><td>S1</td><td rowspan="6">Bolts</td><td rowspan="3">10</td><td>2</td></tr>
<tr><td>S2</td><td>4</td></tr>
<tr><td>S3</td><td>6</td></tr>
<tr><td>S4</td><td rowspan="3">12</td><td>2</td></tr>
<tr><td>S5</td><td>4</td></tr>
<tr><td>S6</td><td>6</td></tr>
</table>

Table 2: Material properties

Material	Yield Strength, N/mm^2	Ultimate Strength, N/mm^2
CFS	329.7	429.2
Wire mesh	418.0	522.7
Bolt	704.3	906.3

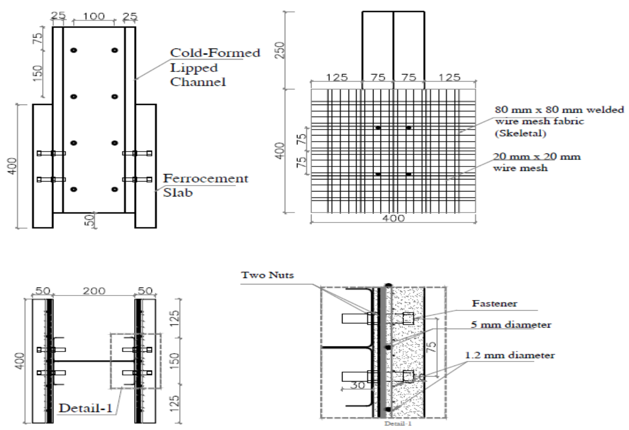

Fig. 1: Layout for push-out test specimen.

Fig. 2: Fixing shear connectors.

Fig. 3: Instrumentation setup.

FINITE ELEMENT ANALYSIS

The numerical simulation using FEM as a tool to simulate the behavior of the tested specimens have been used by many researchers [16-19] to validate the results of the experimental tests. In this paper, the tested shear connectors of composite beams have been analyzed using three dimensional finite element models. The main objectives of the analysis are to validate the accuracy of the load capacity of the experimental tests results. The tested specimens are modeled as finite element analysis by adopting the following assumptions. The steel section and the concrete slab are modeled as elastic-plastic shell (SHELL 43 and SOLID 65) elements. The reinforcing bars both longitudinal and transverse are modeled as smeared in layers throughout the solid 65 (concrete slab) finite elements. A non-linear spring element (COMBIN39 in ANSYS) and (Link8) were used to represent the shear connectors behavior. COMBIN39 was used to resist the normal force between the ferrocement and CFS beam while Link8 works as stirrups in resisting the vertical shear at concrete layer. COMBIN39 was taken as unidirectional element (or nonlinear spring) with nonlinear generalized force-deflection capability that can be used in any analysis. The geometrical modeling of shear connectors is shown in [Fig. 4] and [Fig. 5] where the finite elements mesh for the tested specimen are clearly shown.

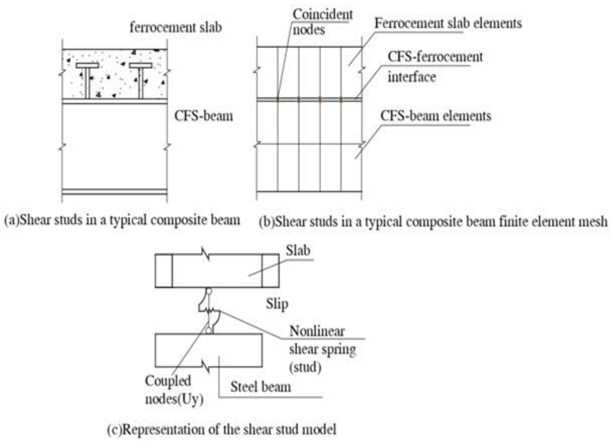

Fig. 4: Modelling of shear connectors.

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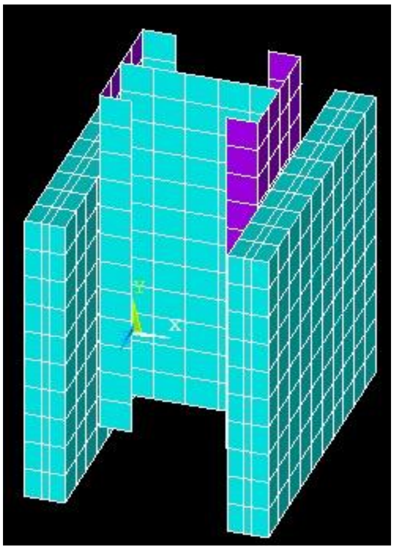

Fig. 5: Typical composite beam FE mesh .

RESULTS AND DISCUSSIONS

Failure mechanism test specimen S1, S2 and S3 (bolts 10 mm Diam)

For test specimens S1, S2 and S3, the failure load from the push-out test were recorded as 71.2 , 72.9 and 75.2 kN per shear connector respectively. The first crack occurred at load 155.5 kN for S1, 170.5 kN for S2 and 174.7 kN for S3. Yielding of the stud element was noticed near the bolts followed by maximum compressive stress reached by ferrocement elements around the bolts. The shear connection failed due bolts yielding and ferrocement crushed. The development of bent to the shear boltsand cracks in ferrocement slab after test are shown in [Fig. 6(a) and 6(b)].

Failure mechanism test specimen S4, S5 and S6 (bolts 12mm Diam)

The test was terminated when the connected slabs are separated from the CFS-beam, all bolts were still intact and a conical concrete failure was noticed around the bolts. The first crack occurred at load 175.3 kN for S4, 180.4 kN for S5 and 181.7 kN for S6. Longitudinal cracks are likely to occur due to high splitting forces caused by shear force. Maximum loads were 74.9, 77.6 and 79.6 kN per shear connector for specimens S4, S5 and S6 respectively. [Fig. 6(b)] shows the conical failure of concrete in compression around the stud and the mode failure in ferrocement slab. It was found that the shear connector has no deformation and rotation as well as no yielding around the bolts hole. This showed that the shear connector was strong enough to provide composite action and to transfer the longitudinal shear force form the ferrocement slab to CFS beam without showing any abrupt failure.

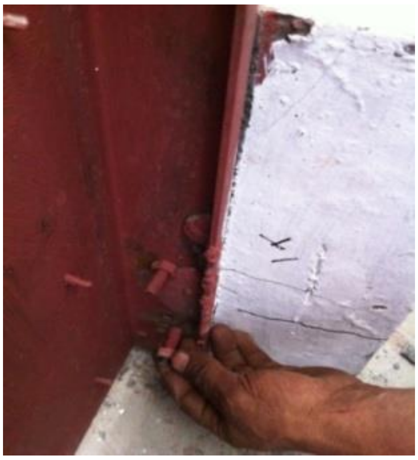

Fig. 6(a): Bending of the bolts.

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Fig. 6(b): Crack on slabs.

Fig. 6(c): Failure in concrete around the bolts.

Comparison between experimental, theoretical and FE results

[Table 3] shows the comparison between experimental, theoretical analysis and finite element results. The results in [Table 3] indicate that the theoretical analysis is closer to the experimental and finite element analysis values. The comparison was made for ultimate load carrying capacity of all shear connectors. The ratios of experimental to predicted ultimate load are in the range between 0.9 to 1.4 while the ratio of the results of finite element analysis to predicted ultimate loads are in the range between 1.0 to 1.2. The slip in finite elements results as shown in [Fig. 7] appears larger than the experimental due to the contact stress between the steel section and the ferrocement slab could not be represented in finite elements model.

Table 3: Comparison of theoretical results with experimental and fea results

Specimen	Test age (day)	f_{cu} at test date (MPa)	$P_{u,exp}$ (kN)	slip at ultimate load (mm)	P_{FE} (kN)	$P_{u,exp}/P_{FE}$	P_{pre} (kN)	$P_{u,exp}/P_{pre}$
S1	36	34.8	284.8	1.9	255	1.1	220.4	1.3
S2	36	35.1	290.2	1.3	292.5	1.0	220.4	1.3
S3	36	33.6	300.6	1.2	272.4	1.1	220.4	1.4
S4	42	34.8	299.5	2.5	282.4	1.1	317.4	0.9
S5	42	34.1	310.1	1.2	267.4	1.2	317.4	1.0
S6	42	33.3	341.4	1.4	328.5	1.0	317.4	1.1

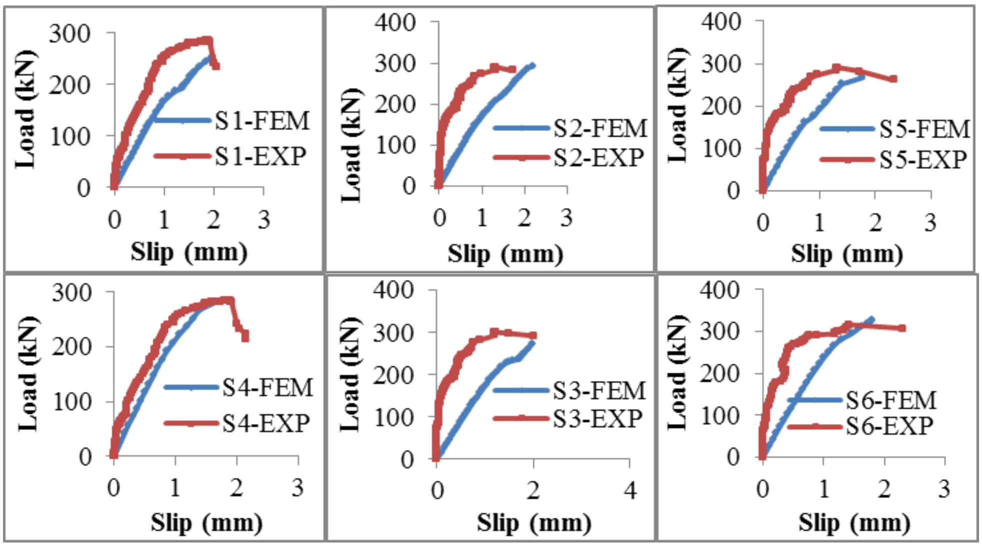

Fig. 7: The comparison between the experimental and FE results.

CONCLUSIONS

From the observations and results of 6 push test specimens, the following conclusions can be drawn:

- The effect of increasing the number of layers of wire mesh in ferrocement slab has not significantly improved the load capacity of shear connectors.
- The FE model and theoretical results agreed well with the results obtained from the experimental push-out tests. The comparison proved to have good agreement with each other.
- The capacity of shear connector in which bolts with 12 mm diameter was the best shear connector considered in transferring shear force into CFS-ferrocement slab interface.

CONFLICT OF INTEREST

There is no conflict of interest.

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FINANCIAL DISCLOSURE

None

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